operated in strictly nonblocking manner in accordance with the invention if $m \geq 3 * n - 1$. Also in accordance with the invention, a three-stage network having more middle switches than $2 * n_1 + n_2 - 1$ is operated in strictly nonblocking manner even if some multicast connections are set up by using more than two middle switches as long as each connection has available links into at least two middle switches and there are always at least $n_1 - 1$ unused links from each input switch to middle switches, after each connection is set up.

BRIEF DESCRIPTION OF DRAWINGS

FIG. 1A is a diagram of an exemplary three-stage symmetrical network with exemplary multicast connections in accordance with the invention; and FIG. 1B is high-level flowchart of a scheduling method according to the invention, used to set up the multicast connections in the network 100 of FIG. 1A.

FIG. 2A is a diagram of a general symmetrical three-stage strictly nonblocking network with n inlet links in each of r input stage switches and $m = 3 * n - 1$ middle stage switches that are used with the method of FIG. 1B in one embodiment; and FIG. 2B is a diagram of a general non-symmetrical three-stage strictly nonblocking network with n_1 inlet links in each of r_1 input stage switches, n_2 outlet links in each of r_2 output stage switches, and $m = 2 * n_1 + n_2 - 1$ middle stage switches that are used with the method of FIG. 1B in one embodiment;

FIG. 3A is intermediate level flowchart of one implementation of the method 140 of FIG. 1B; FIG. 3B shows an exemplary $V(8,3,9)$ network with certain existing multicast connections; FIG. 3C shows the network of FIG. 3B after a new connection is set up by selecting one middle switch in the network, using the method of FIG. 3A in one implementation; and FIG. 3D shows the network of FIG. 3C after another new connection is set up by selecting two middle switches in the network, using the method of FIG. 3A in one implementation.

FIG. 4A is another intermediate level flowchart of one implementation of the act 142 of FIG. 3A. FIG. 4B is low-level flowchart of one variant of act 142 of the method of FIG. 4A; and FIG. 4C illustrates, in a flowchart, pseudo code for one example of scheduling method of FIG. 4B. FIG. 4D implements, in one embodiment, the data structures used to store and retrieve data from memory of a controller that implements the method of FIG. 4C.

FIG. 5A is a diagram of an exemplary three-stage network where the middle stage switches are each three-stage networks; FIG. 5B is high-level flowchart, in one embodiment, of a recursively scheduling method in a recursively large multi-stage network such as the network in FIG. 5A.

FIG. 6A is a diagram of a general symmetrical three-stage network with n inlet links in each of r input stage switches and $m = 4*n-1$ middle stage switches; and FIG. 6B is high-level flowchart, in one embodiment, of a scheduling method used to set up multicast connections the network of FIG. 6A, according to the invention.

FIG. 7A is a diagram of a general symmetrical three-stage network with n inlet links in each of r input stage switches and $m = x*n$ middle stage switches for $x \geq 2$; and FIG. 7B is high-level flowchart, in one embodiment, of a scheduling method used to set up multicast connections in the network of FIG. 7A, according to the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention is concerned with the design and operation of multi-stage switching networks for broadcast, unicast and multicast connections. When a transmitting device simultaneously sends information to more than one receiving device, the one-to-many connection required between the transmitting device and the receiving devices is called a multicast connection. A set of multicast connections is referred to as a multicast assignment. When a transmitting device sends information to one receiving device, the one-to-one connection required between the transmitting device and the receiving device is called unicast connection. When a transmitting device simultaneously sends information to all the available receiving devices, the one-to-all connection

required between the transmitting device and the receiving devices is called a broadcast connection.

In general, a multicast connection is meant to be one-to-many connection, which includes unicast and broadcast connections. A multicast assignment in a switching network is nonblocking if any of the available inlet links can always be connected to any of the available outlet links. In certain multi-stage networks of the type described herein, any connection request of arbitrary fan-out, i.e. from an inlet link to an outlet link or to a set of outlet links of the network, can be satisfied without blocking with never needing to rearrange any of the previous connection requests. Depending on the number of switches in a middle stage of such a network, such connection requests may be satisfied without blocking if necessary by rearranging some of the previous connection requests as described in detail in U.S. Patent Application, Attorney Docket No. M-12158 that is incorporated by reference above.

Referring to FIG. 1A, an exemplary symmetrical three-stage Clos network of sixteen switches for satisfying communication requests, such as setting up a telephone call or a data call, between an input stage 110 and output stage 120 via a middle stage 130 is shown where input stage 110 consists of four, three by eight switches IS1-IS4 and output stage 120 consists of four, eight by three switches OS1-OS4, and middle stage 130 consists of eight, four by four switches MS1-MS8. Such a network can be operated in strictly non-blocking manner, because the number of switches in the middle stage 130 (i.e. eight switches) is equal to 3*n-1, where the n is the number of links (i.e. three inlet links) of each of the switches in the input stage 110 and output stage 120. The specific method used in implementing the strictly non-blocking connectivity can be any of a number of different methods that will be apparent to a skilled person in view of the disclosure. One such method is described below in reference to FIG. 1B.

In one embodiment of this network each of the input switches IS1-IS4 and output switches OS1-OS4 are crossbar switches. When the number of stages of the network is one, the switching network is called single-stage switching network, crossbar switching network or more simply crossbar switch. A $(N * M)$ crossbar switching network with N inlet links and M outlet links is composed of NM cross points. As the values of N and